AASHTO-77
26-1

THE USE OF FABRICS IN
FOREST SERVICE ROAD CONSTRUCTION

by

Adrian Pelzner
Chief Materials Engineer
Forest Service, USDA
Washington, D.C.

and

John E. Steward
Leader, Engineering Soils and Materials Group
Forest Service, USDA
Portland, Oregon

Paper Prepared for Presentation
at the
Annual Meeting of AASHTO
Atlantic City, New Jersey
October 31, 1977 2-5 P.M.
AASHTO Subcommittee on Materials

SJ NKW

Engineering Fabrics-an Abundance of Alternates

It is becoming increasingly apparent that fabrics are an important highway engineering material. Very significant cost savings and long term benefits can be obtained by the proper use of fabrics in highway construction and maintenance. It is also apparent that highway engineers wanting to use fabrics have before them a bewildering array of alternates. The following is a listing of just some of the choices and considerations that would have to be made.

1. Type of use--

   Filtration, separation, subgrade restraint, earth strengthening, erosion control, waterproofing membrane, pavement reinforcement

2. Type of fiber--

   Polypropylene, polyester, polyethylene, polyvinylidene chloride, nylon, continous fibers, short fibers

3. Manufacturing process--

   Knitted, woven, non-woven--heat bonded, spun bonded, chemical bonded, needle punched

4. Manufacturers--

   Advance Construction Specialties, Carthage Mills, Celanese, Crown Zellerbach, Dupont, Erco, Gulf States Paper, Menardi-Southern, Monsanto, Philips, Staff Industries

5. Thickness--

   15-190 mils

6. Weight--

   4-19.4 oz/yd^2

7. Width--

   6-84 ft

8. Length--

   50-3000 ft

9. Test methods--

   Equivalent size opening, permeability, mullen burst, stiffness, tear resistance, grab and strip tensile strength, tear strength-constant extension, tear strength-constant transverse extension, trapezoidal tear, seam strength, abrasion resistance, gradient ratio

10. Cost--

Woven	(7 oz/yd^2)	.12-.25 ft^2
Nonwoven	(4 oz/yd^2)	.05-.08 ft^2
	(12 oz/yd^2)	.15-.24 ft^2

In order to make an intelligent fabric selection choice from these many options the highway engineer needs to answer three seemingly simple questions:

1. Is the intended use of the fabric cost effective?

2. What physical and chemical characteristics should the fabric have for the intended use?

3. What are the proper range of values for these characteristics?

Although these questions are simple, authoritative answers based on well documented experience and rigorous scientific analysis are lacking. Nevertheless the manufacturers, salesmen and users are not waiting for complete authoritative answers. The use of fabrics in road construction is increasing and it is increasing at an accelerating rate. This is not to say the search for knowledge on the use of fabrics is being ignored. The Federal Highway Administration has initiated a major research effort on test methods and use criteria for filter fabrics. The AASHTO Subcommittee on Materials, ASTM Committees D-18 on Soil and Rock and D-13 on Textiles are all establishing working groups for the development of appropriate test methods and specifications for fabrics as an engineering material. The manufacturers themselves have ongoing, in-house efforts to develop and improve their products for specific highway oriented end uses. Another major effort in the search for high quality information and well documented experience on the use of fabrics has been initiated by the USDA, Forest Service.

The Forest Service Use of Fabrics for Low Volume Roads

The basic mission of the Forest Service is to carry out the Federal responsibility for the wise use of Forest and related watershed lands. These forested lands comprise one-third of the total land area of the United States. Some 187 million acres of forested lands are under direct Forest Service management. The extent and location of Forest Service lands are shown in Figure 1. The lands are managed for five different and sometimes conflicting purposes:

1. Timber
2. Watershed
3. Forage
4. Wildlife
5. Recreation

To effectively manage these vast lands for these purposes the Forest Service is building one of the largest transportation systems in the world. Table 1 shows the existing and planned mileage of this system.

The transportation system is located over a wide range of terrain. For the most part, however, the system is located in remote, steep mountainous terrain, frequently in unstable, erodible, fragile soils. The terrain is susceptible to flash floods, disastrous landslides, slumps and mud flows. These tough road building conditions are the very reasons behind the Forest Service's evaluation of fabrics. If fabric can be substituted for all or a portion of the high quality, expensive, imported construction materials that are needed to combat these tough conditions, then the opportunity for savings are enormous. As shown in Table 1 the Forest Service is building and reconstructing approximately 10,000 miles of road a year. Even relatively minor cost efficiencies have the potential for considerable Service-wide savings. Forest Service engineers were quick to recognize the potential advantages of fabrics.

As with any new construction material, the fabrics are being evaluated under a trial use program. The principal types of Forest Service uses for fabrics will be discussed in more detail later in this report. However, briefly stated these uses involve:

1. Filtration (drainage)
2. Separation
3. Subgrade Restraint
4. Earth Strengthening
5. Erosion Control

Various administrative regions of the Forest Service have fabric test installations in place or are planning them for all or some of the cited uses. The largest program for evaluating fabrics in the Forest Service is taking place in the Pacific Northwest (Region 6).

Trial Use Program

In Region 6, fabrics are being evaluated under a formal trial use program. The program is described in the Forest Service manual (designation: FSM 7175). The trial use program involves four steps: 1) a project proposal outlining the intended use, projected cost and benefits, and proposed monitoring to determine costs and benefits; 2) a report on the construction; 3) a report on the monitoring of the project to determine if it did or did not achieve the original project goals; 4) a final report with recommendations for design guidelines, specifications, and future use of the material.

Extent and Location of Forest Service Lands

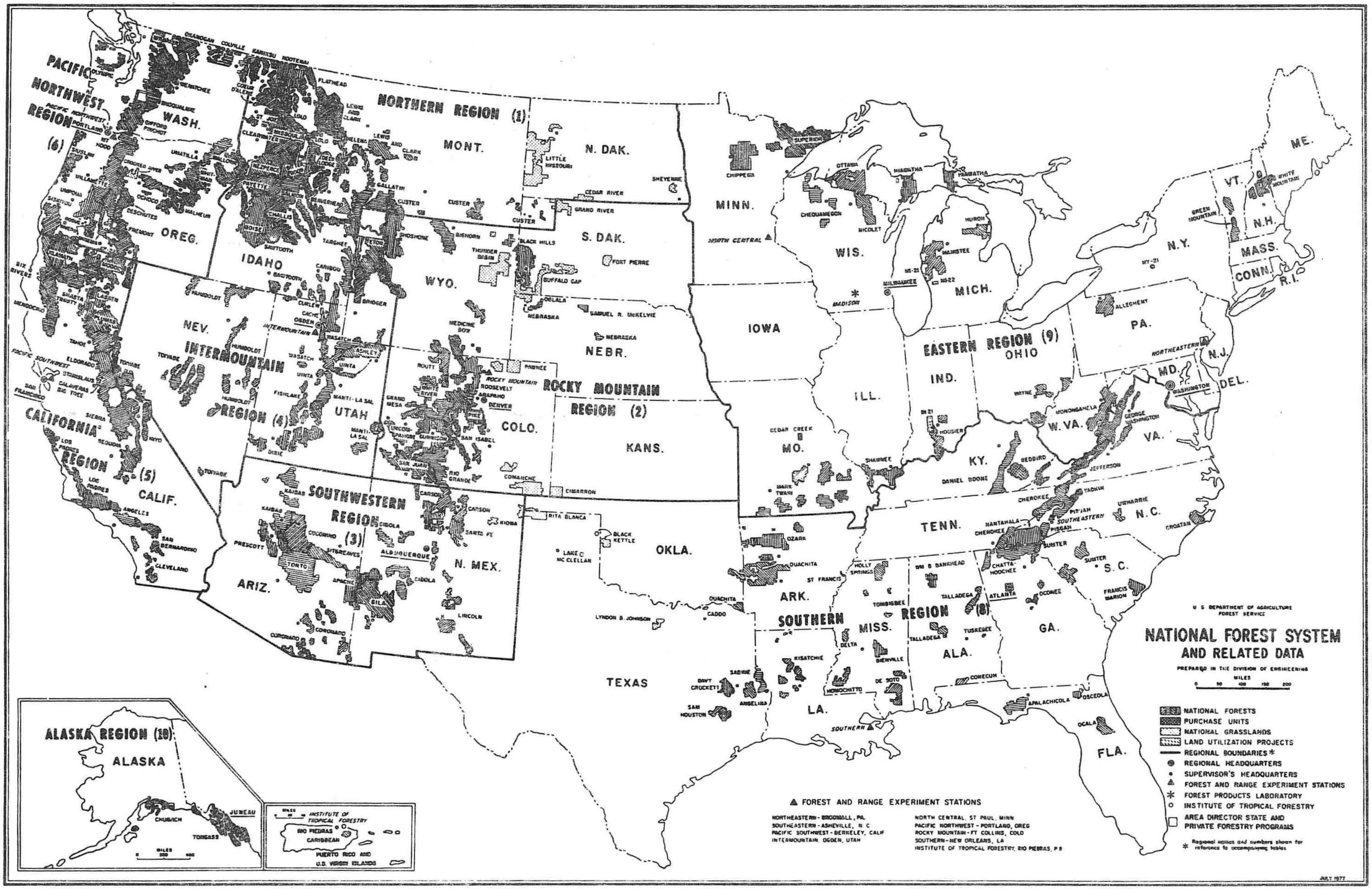


Figure 1

Mileage and Investment of
The Forest Service Transportation System

Category	Miles	Approximate Investment (Dollars)
Existing Road System	220,000	3,260,000,000
Planned Additional Miles	117,000	4,680,000,000
Approximate Miles Constructed and Reconstructed Annually	10,000	389,000,000 1/
Maintenance	220,000	78,000,000 2/

1/ FY 1977

2/ FY 1978

Table 1

Most new products go through three distinct phases in moving from the conceptual to the full usage level.

Phase I - Trial Use: First usage to develop design criteria, construction methods, economic feasibility, and specifications. Intensive monitoring, instrumentation and analysis is included in this phase. Actual cost for the project may exceed conventional methods by 100 percent.

Phase II - Special Use: Second usage to determine and evaluate appropriate costs and to test criteria, methods, and specifications developed in Phase I. Second usage is a field usage under a minimum of experimental controls to develop realistic criteria and costs.

Phase III - General Use: Full usage in accordance with cost, criteria guidelines, and specifications developed in Phase I and evaluated in Phase II. The projects in Phase III are no longer considered trial use.

All phases may not be used or required within the Forest Service depending upon the adequacy of work by other agencies or individuals.

Functions of Engineering Fabrics

Using the previously described trial use program, the first trial installations of both woven and non-woven fabric took place in Region 6 in 1974. In Region 6 fabrics have been used for: 1) filters for sub-surface drainage; 2) separation layers to prevent subgrade soil contamination of base layers; 3) subgrade restraint for weak subgrades; 4) earth strengthening to build retaining walls; and 5) erosion control.

The essential functions of the fabric for these uses are:

1. Filtration: Filtration is the process of allowing water to easily escape from a soil unit while retaining the soil in place. The two primary functions of fabric used for filtration are: 1) remove water, and 2) retain soil.

2. Separation: Separation is the physical process of preventing two dissimilar materials from mixing. The most common usage would be to prevent or minimize the movement of weak subgrade soils into aggregate bases. The primary function is: prevent mixing.

3. Subgrade Restraint: Subgrade restraint is the process of preventing or reducing soil movement and strain by fabric confinement. The primary function is to: restrain soils (against shear failure at low stress).

4. Earth Strengthening: The concept of earth strengthening involves the use of the fabric to increase the strength of a fabric-soil system. The primary function is: strengthen earth.

5. Erosion Control: Erosion control is the use of fabrics to: 1) prevent movement of surface soils; 2) remove soil from water on the earth's surface, and 3) use of fabrics to promote soil protecting growth. The primary function is to: prevent surface movement.

Findings, Selection Criteria, Design Procedures, Recommendations and Other Relevant Information

In the relatively short time that fabrics have been used by the Forest Service, certain findings, procedures, recommendations, and other relevant information have been developed and codified. This information was developed from analyses, literature searches, discussions with fabric manufacturers, other personal communication and the previously described trial use program for fabrics. Only a summary of the more important findings is presented in this paper. Mathematical analyses, back-up information, lengthy explanations, diagrams, tables of data, and design specifications have been purposely omitted in the interest of brevity and clarity. Also, in the interest of brevity the findings presented herein are in outline form and are listed under the various functional uses of the fabrics.

Filtration:

The Forest Service along with many other road building agencies has long used graded aggregate filters to drain wet areas. Forest Service experience with graded filters indicates frequent failures due to plugging, clogging and inadequate permeability to rapidly remove the collected water. These failures are due to a number of reasons: frequently changing soil conditions, non-availability of specified gradations, poor construction practices, and limited sampling, testing and inspection capabilities. In fact it has been conservatively estimated that graded aggregate filters have less than a 50 percent chance of functioning properly. Contrasting this is the Forest Service success ratio of near 100 percent when using plastic filter cloth and relatively inexpensive free draining, open graded rock. Plastic filter cloths have been used in subdrainage trenches, blankets, behind rock buttresses, under riprap, around vertical gravel drains and many other applications where graded filters are normally used. Both woven and non-woven fabrics have been used for filtration purposes.

Woven Filter Cloths-

Regional specification 6-47, for woven plastic filter cloth has been reproduced and is shown in the appendix to this paper. A very important characteristic of the woven filter cloths is the Equivalent Opening Size (EOS). The EOS is the number of the U.S. standard sieve having openings closest in size to the filter fabric openings. Several important design requirements for woven filter cloth relate to EOS and are as follows:

1. Filter cloth adjacent to native materials containing 50 percent or less passing the No. 200 sieve:

$$\frac{\text{85 percent size of soil (mm)}}{\text{opening size of EOS (mm)}} \geq 1.0$$

2. Filter cloth adjacent to all other type soils:

   EOS no larger than No. 70 sieve

3. No cloth shall be specified with an open area less than 4 percent

   Note: Open area is defined as the summation of the open areas divided by the total area of the filter cloth.

4. No cloth shall be specified with an EOS smaller than a No. 100 sieve. Filter fabrics should not be used for soils having sizes finer than 85% passing the No. 20 sieve.

5. The design requirements for most filtration projects will be satisfied for woven fabrics having a 70 to 100 EOS.

6. A 30 to 70 EOS will be required only when coarse sands and gravels with high flow potentials are encountered.

Non-woven Filter Cloths-

In Region 6 some limitations have been placed on the use of non-wovens for filtration purposes. These limitations recommend the use of non-woven for "less critical" and less severe" filtration projects.

Non-wovens are not recommended for:

1. Critical-projects where failure of the filter could result in failure of an expensive or environmentally sensitive portion of a project.

2. Severe-conditions of moderate to high seepage out of erodible soils.

Non-wovens can be used for: 1/

1. Less critical-projects where failure of the filter would lead to a decreased effectiveness of the system or damage to a limited portion of a project, and which is accessible to repair.

1/ Laboratory filtration testing should be performed using the proposed fabric and soil from the proposed drainage site.

2. Areas of casual seepage where the water entering the system comes primarily from surface infiltration rather than seeping ground water under hydraulic gradient.

These limitations are not to be construed as an indication that non-wovens cannot perform as effective filter systems. There are many filtration projects where non-woven fabrics have performed well. The limitations have been placed because of the uncertainty of the design and specification criteria.

For woven fabrics the EOS and percent open area are directly measureable, predictable and locked into the fabric during the weaving and calendering process. Consequently, the design and specifying engineer can rely on these properties. Non-woven fabrics are manufactured by extrusion and random orientation of fibers in the fabric. The resulting apparent EOS and percent open area in non-wovens are variable. The relative "fixing" of these properties depends on fabric weight and bonding process. Also non-wovens have a generally higher elongation under load. The apparent EOS for non-wovens are more subject to change under load than the woven fabrics. Consequently, tests for EOS and percent open area may not be appropriate for non-woven filter fabrics.

The gradient ratio (G.R.) test appears to be more suitable for evaluating and specifying non-woven fabric filters. The gradient ratio is the ratio of the hydraulic gradient over the fabric and one inch of soil immediately next to the fabric--to the hydraulic gradient over two inches of soil between one and three inches above the fabric. The test is performed in a constant head permeameter with a four inch thick soil sample over the fabric and open drain rock below, under a head of about 12 inches. The G.R. test is still in the developmental stage and, at this time, only a limited number of testing facilities have the capability to run the test. Typically the G.R. test takes about 10 days to run but may take as much as three or four weeks.

The algebraic expressions for the G.R. test is:

$$G.R. = \frac{i_f}{i_s}$$

Where:

G.R. = The gradient ratio

i_f = The hydraulic gradient over the fabric and one inch of soil immediately next to the fabric

i_s = The hydraulic gradient over two inches of soil between one and three inches above the fabric

The Corps of Engineers recommends the G.R. of any non-woven filter cloth should not exceed 3.

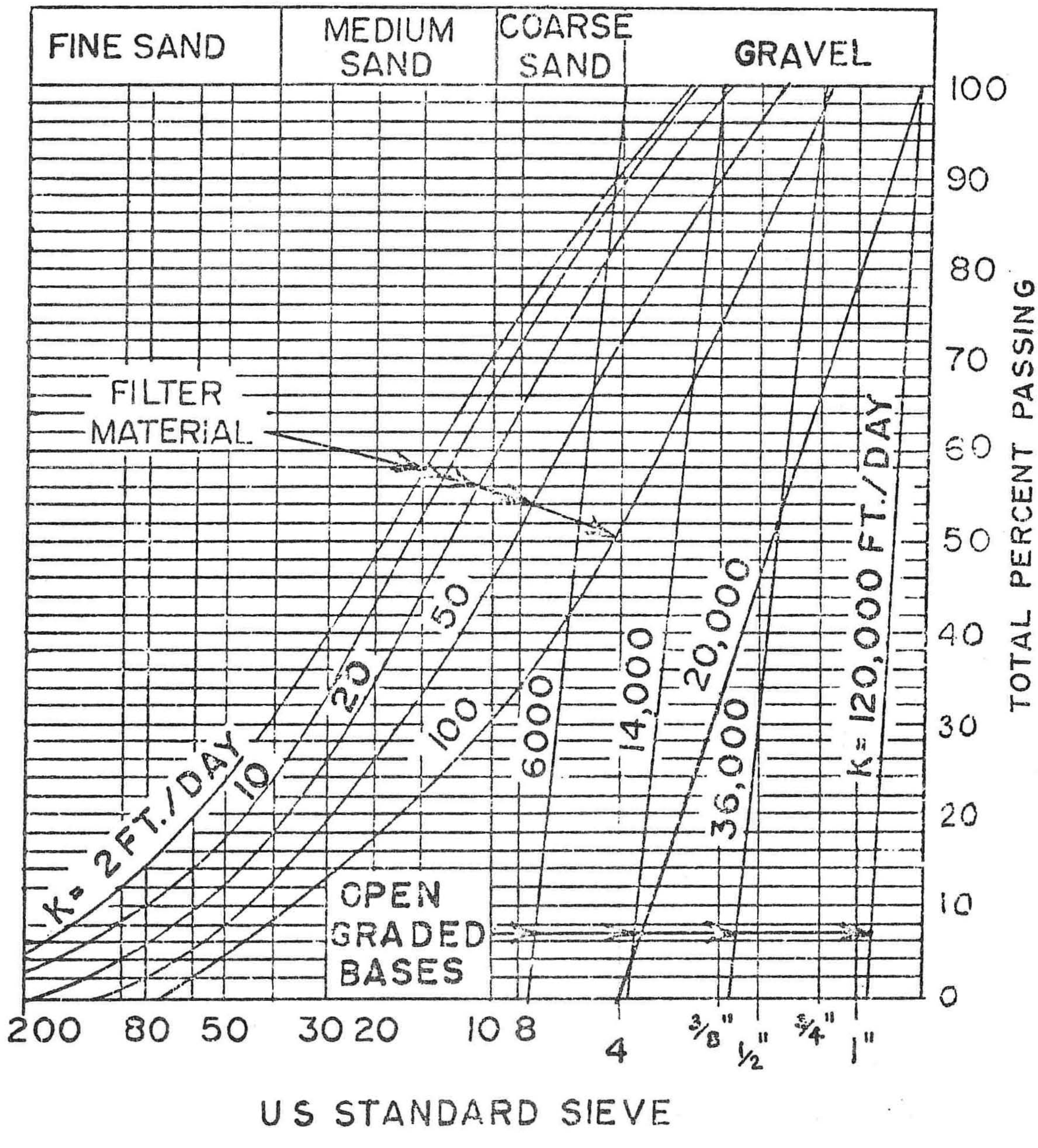
At present the recommendations for when and where to use the non-woven fabrics for filtration projects are based on engineering judgement. However, it should be noted that non-woven fabrics are approximately one-half the cost of woven fabrics of the same weight. In Region 6 it is expected the limitations for non-wovens will be lessened or removed in accordance with experiences gained through the trial use program and in accordance with the improvement and increased use of gradient ratio testing.

Drain Rock for Filter Cloths-

A very important advantage obtained from using fabrics for filtration is the lessening of gradation requirements for drain rock within the fabrics. Without fabrics well graded aggregate filters with very exacting gradation requirements must be specifically designed to remove water and prevent clogging from the surrounding native soils. The cost for obtaining such "custom made" gradations is very high. Furthermore at remote construction locations the required gradations are difficult to manufacture and blend. Frequently it is necessary to compromise from a gradation that is specified to some other "near" gradation that is practical to obtain. Finally because of the need for preventing clogging, fine material must be included in the gradation thereby greatly reducing the overall permeability of the filter. This often leads to a limited area of influence of the drainage system and a low rate of water removal. With all these difficulties it is little wonder that graded aggregate filters have such a poor performance record.

On the other hand when filter fabrics are used, the gradation requirements for the drain rock are minimal. The function of the fabric is to permit the water to pass through and to prevent the native soil from moving into the drain with subsequent clogging. Consequently, there is no need for permeability reducing fine material in the drain rock. Furthermore, a great variety of readily available aggregate material can be used such as pea gravel, uniformily graded crushed rock and open graded base course material. Such materials have permeabilities ranging from 6,000 to 120,000 feet per day. This is far in excess of the permeabilities of well graded filters which may only range 10 to 100 feet per day. Figure 2 shows the range of permeabilities for several different gradations of graded filter materials as compared to the permeabilities for several gradations of open graded bases.

There are some other advantages for using high permeability, open graded drain rock with filter cloth. This cloth-aggregate combination allows the use of thinner and more hydraulically efficient drainage layers. Furthermore, open graded drain rock normally has enough flow capacity to eliminate the need for perforated plastic pipes for up to 100 feet of subdrains.



Typical Gradations and Permeabilities of Several Open-graded Aggregates and Several Filter Materials.

Figure 2

Separation:

The concept of separation is a physical process of preventing two dissimilar materials from mixing. The most common usage would be to prevent or minimize the movement of weak subgrade soils into aggregate bases. The process of subgrade contamination of the base can be readily observed on any existing road by excavating test holes through the base and subgrade. The extent and rate of intrusion and contamination depends primarily on the soil and base gradation, construction process, moisture conditions, and traffic.

In Region 6 it is not uncommon to observe four to eight inches of base contamination. It only takes about 20% by weight of subgrade soil mixed into the dense graded bases to reduce their bearing capacity to that of the soil. Figure 3 illustrates the total aggregate thickness required to serve the same traffic with and without base contamination. When contaminated by clay or silty soils, aggregate base will change from an initial CBR of 80 (a value = 0.13) to a CBR value of about 15 (a value = 0.09). For the example in Figure 3, 2.5 inches of additional dense graded base is required in the contaminated section to obtain the same structural capacity as a section without contamination. The value of the separation layer is equal to the cost associated with the additional base.

There are a number of ways to prevent or reduce the mixing of dissimilar materials. Some of these are sand blankets, properly graded bases, thicker sub-bases, lime and Portland cement treated subgrades, and filter fabrics. An engineering analysis should be made to determine which alternate is most cost effective.

The information required to determine the cost effectiveness of fabrics or other separation layers is: a) the amount of contamination for the design without separation layer; b) the amount of contamination with a separation layer; and c) the cost of the separation layer compared to the cost of the additional thickness required to account for the contamination. Information on the amount of contamination to expect on a project without fabrics can be gained by test excavations in existing roads in areas with similar construction, soil and traffic conditions.

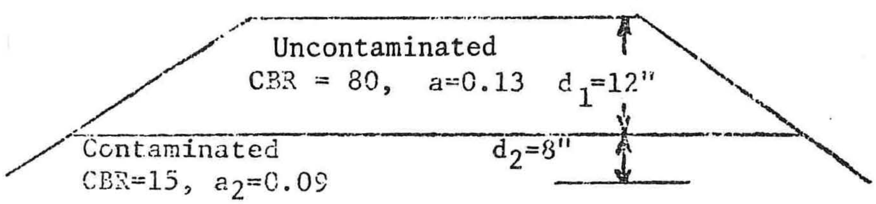
The amount of contamination a separation layer will prevent cannot be estimated due to a lack of documented field and laboratory testing. Until further documentation is made fabric separation installations should be designed on the basis of elimination of 75% of the contamination by use of fabrics and 100% of the elimination using lime or Portland cement treatment.

The following procedure is for estimating the appropriateness and cost effectiveness of fabric as a separation layer:

1. Estimate the thickness of the contaminated zone by making test excavations in existing roads with similar construction, soils, and traffic to the project being designed.

a.) As Constructed
and Uncontaminated

structural number
sn = ad
sn = (0.13)(20) = 2.60



b.) Contaminated

$sn = a_1 d_1 + a_2 d_2$
$sn = 1.56 + .72 = 2.28$
sn Difficiency
$= 2.60-2.28=0.32$
Additional Base Required
$$\frac{0.32}{0.13} = 2.5''$$

- Example Calculation for Additional Base Required due to contamination from poor subgrade.

Figure 3

2. Assign a structural value ("a" value) to the contaminated and uncontaminated layers.

3. Calculate the thickness of the structural section required with and without contamination.

4. The structural cost of the contamination is equal to the difference in thickness between the structural systems with and without contamination.

5. The conventional design without fabrics should include additional thickness required by the contamination, with the additional thickness being sub-base or base material.

6. The fabric separation design should assume the fabric will prevent 75% of the contamination. Therefore, the fabric section would consist of the fabric plus the 25% of the additional sub-base or base due to contamination without fabric plus the originally designed structural section.

7. A cost analysis of the systems with and without the separation layer (comparison of structural sections in steps 5 and 6) will assist in the decision on the cost effectiveness of the use of fabrics.

8. Compare the cost of preventing contamination by adding lime or Portland cement to the subgrade.

9. Choose the most cost effective system for preventing or minimizing separation.

Subgrade Restraint:

Subgrade restraint is a process of preventing or reducing soil movement and soil strain by use of fabrics for confinement. The subgrade restraint mechanism will predominate only for weak soils loaded (stressed) to levels at which the soil would fail or rut without fabrics. The economics of using fabrics to reduce structural thickness based on the restraint mechanism will control only for subgrades with a CBR less than or equal to 2 or 3. For subgrades with CBR greater than 2 or 3, the separation or filtration function will control.

Naturally occurring soils have a wide variation in soil strength. Failures can be expected to start at the weakest soil area and rapidly progress throughout a wide area. It appears appropriate to determine strength in the field using rapid means to determine the lower limit of soil strength and to design so as to prevent failure in the weakest soil unit. Based on these considerations, work done by research investigators and experience gained in trial use projects the following procedure is recommended for design of low volume roadways using fabrics for subgrade restraint:

1. Visually segment the road into logical construction segments in the field, taking into consideration soil type, vegetation, road grade, terrain slopes, etc.

2. Determine the soil strength in the field using the cone penitrometer (C approximately equals cone value divided by 10 or 11) and/or vane shear (C is read directly).

3. Make the strength determination at 2 or 3 separate places where the soil appears to be the weakest. Make 6 to 10 strength readings at two depths (0-9 inches and 9-18 inches) at each sample site (sample site is approximately 3 feet in diameter).

4. Determine the design strength as the 75th percentile strength for each set of readings at each depth. The 75th percentile is the strength at which 75 percent of the soil strength readings are higher than this value.

5. Determine the maximum single wheel load, maximum dual wheel load, and the maximum dual tandem wheel load anticipated for the road during the design period.

6. Determine the required aggregate thickness from the load-stress depth curves (Figure 4-A, 4-B, 4-C) for each maximum loading. Enter the curve with stresses equal to 2.8, 3.3, 5.0 and 6.0 times the design strength for each depth at each location.

7. Plot the aggregate thickness for each test location to scale by station on a road profile sheet (plot only the greatest aggregate thickness determined from either the shallow or deep strength readings).

8. Show the field determined road segments on the profile. Connect the plotted 75th percentile aggregate thickness readings with straight lines (2.8, 3.3, 5.0 and 6.0 C).

9. Select the design thickness and design road segments visually from the plot of the aggregate thicknesses. The design depth and design segments should be to the next highest 1 inch thickness. The strengths and aggregate thicknesses can aid in the selection of design road segments.

The significance of the thicknesses determined from the charts using various values of C are:

2.8 C is the stress level on the subgrade at whick very little rutting will occur under a great amount of traffic (greater than 1000 18K axle equivalencies) without fabric.

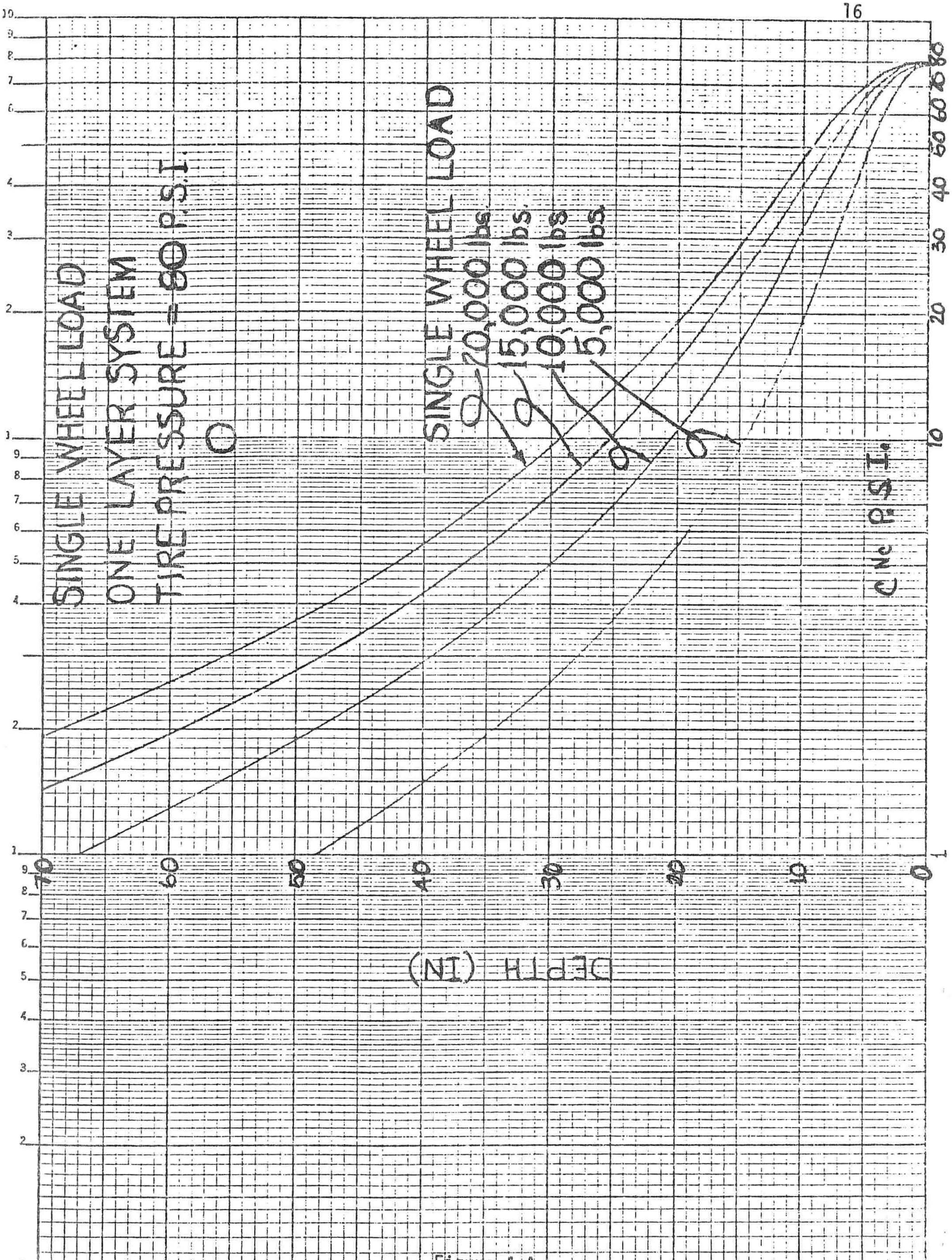

SINGLE WHEEL LOAD
ONE LAYER SYSTEM
TIRE PRESSURE = 80 P.S.I.
SINGLE WHEEL LOAD
20,000 lbs.
15,000 lbs.
10,000 lbs.
5,000 lbs.
C Nc P.S.I.
DEPTH (IN)

Figure 4-A

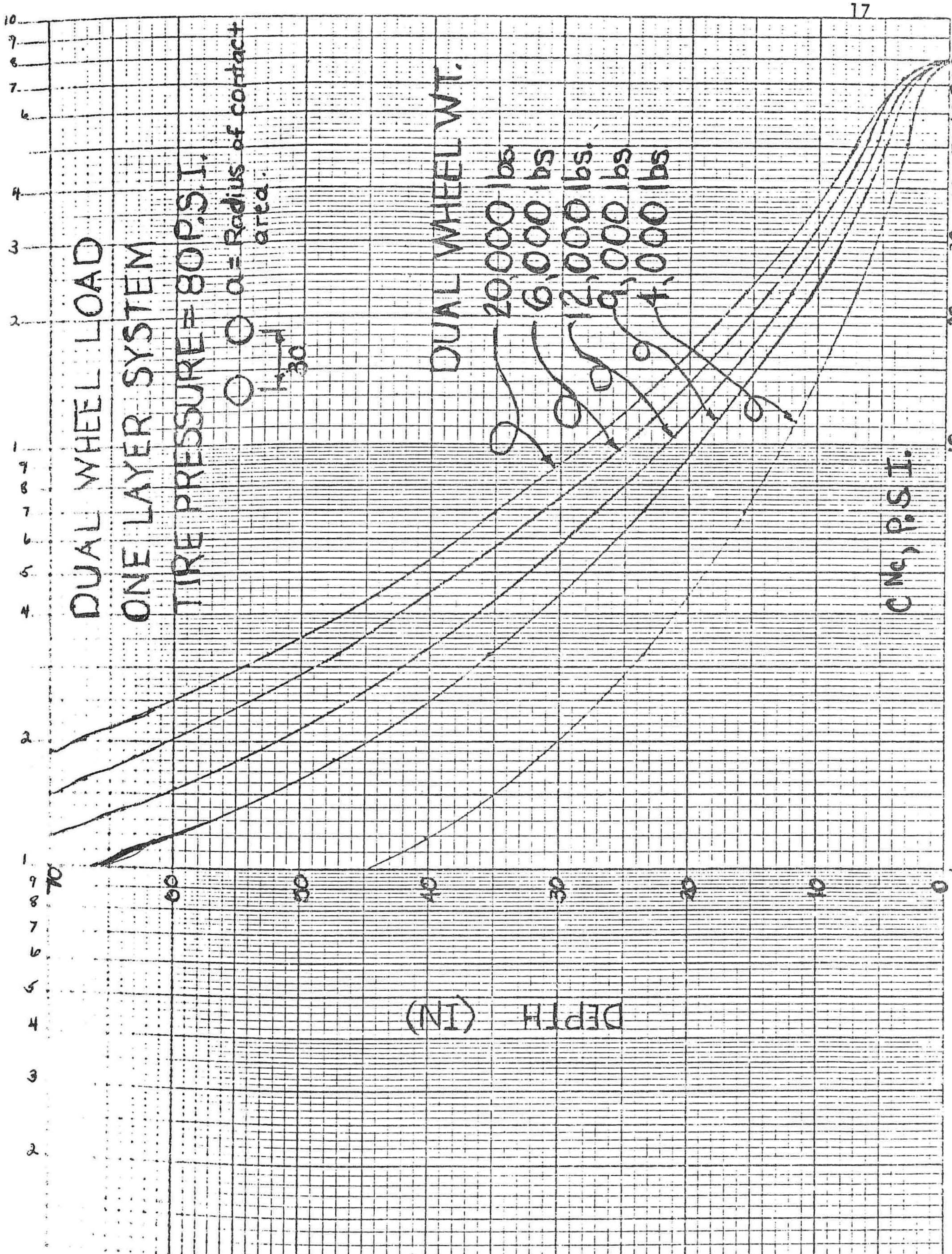

DUAL WHEEL LOAD
ONE LAYER SYSTEM
TIRE PRESSURE= 80 P.S.I.
a = Radius of contact area
30
DUAL WHEEL WT.
20,000 lbs
16,000 lbs
12,000 lbs
8,000 lbs
4,000 lbs
CNc, P.S.I.
DEPTH (IN)
70
60
50
40
30
20
10
0
80

Figure 4-B

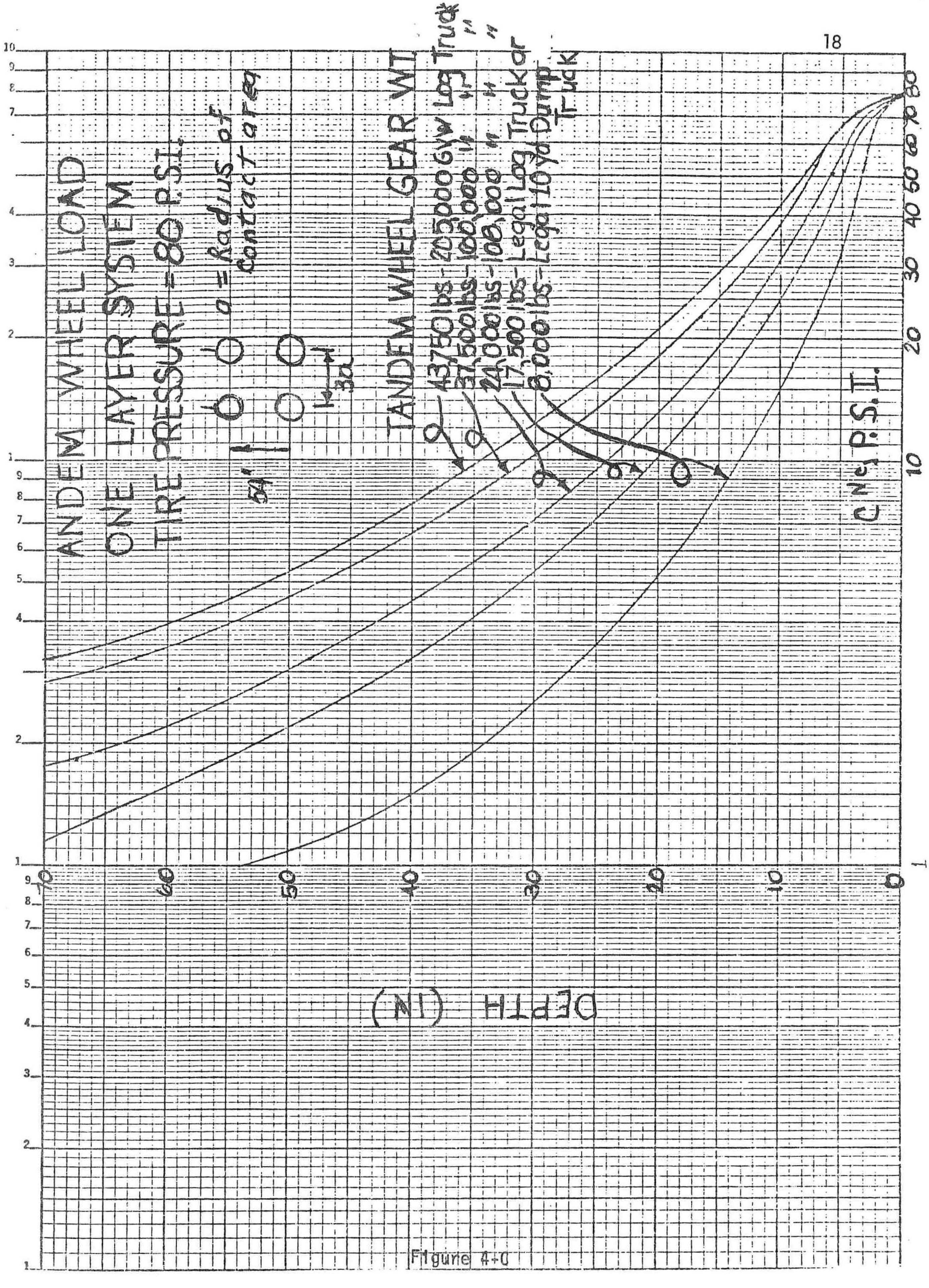

ANDEM WHEEL LOAD
ONE LAYER SYSTEM
TIRE PRESSURE = 80 P.S.I.
a = Radius of contact area
3a
5a
TANDEM WHEEL GEAR WT.
43750 lbs - 205000 GVW Log Truck
37,500 lbs - 100,000 " "
24,000 lbs - 100,000 " "
17,500 lbs - Legal Log Truck or
8,000 lbs - Legal 10 yd Dump Truck
C N, P.S.I.
DEPTH (IN)

Figure 4-0

3.3 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies), without fabric.

5.0 C is the stress level at which very little rutting would be expected to occur at high traffic volumes (greater than 1000 18K equivalency axles) using fabric.

6.0 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies) using fabric.

A great amount of rutting is considered to be a 4 inch or greater rut. Very little rutting is considered to be less than 2 inches of rutting extending into the subgrade.

Other factors:

1. If more rutting occurs during construction than was designed for, the thickness should be increased at least as much as the thickness difference between 2.8 C and 3.3 C.

2. Surface deflections at stress levels of 3.3 C without fabric and 6.0 C with fabric will be equal.

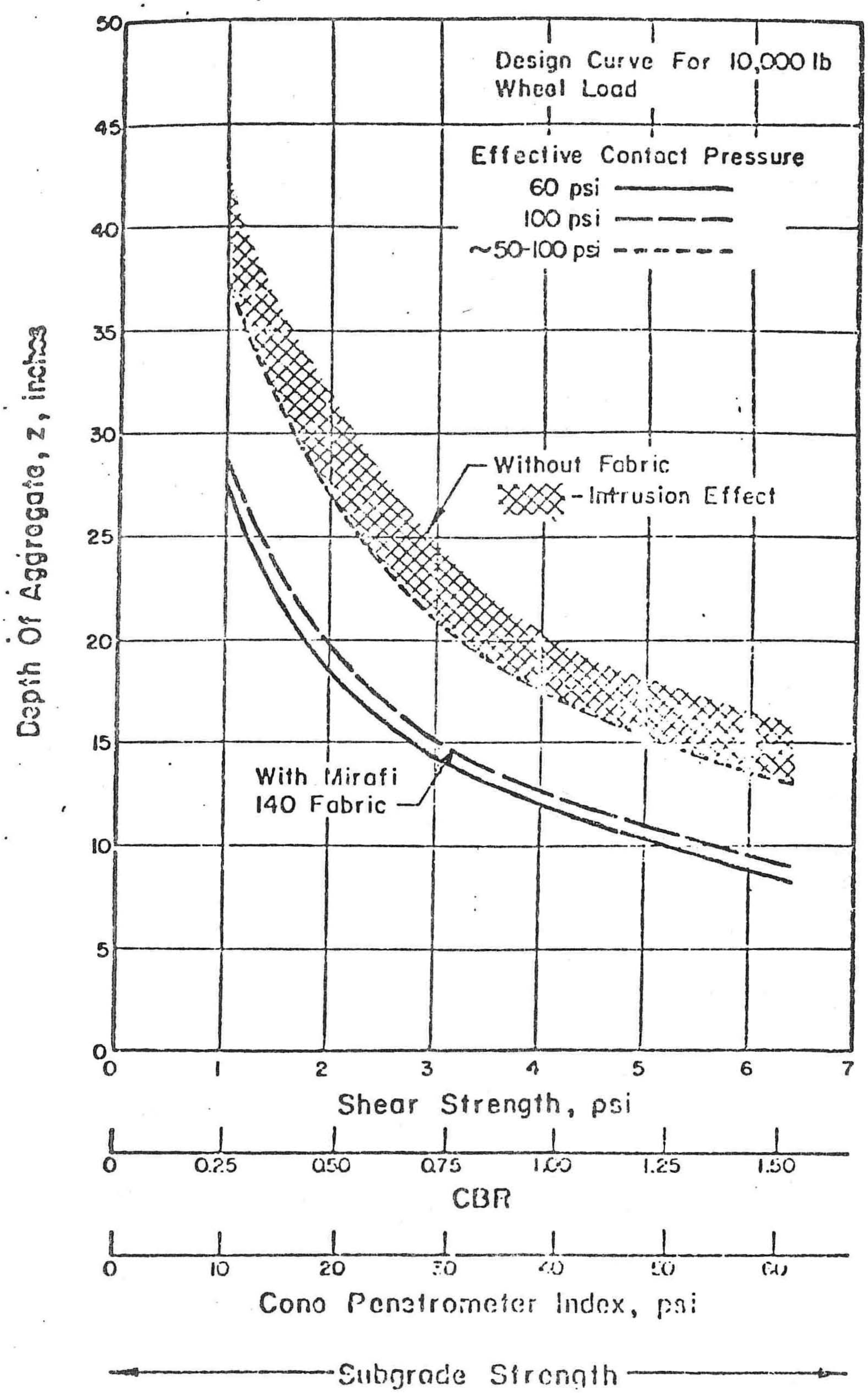
3. Roads on very soft soils are usually weakest at the time of construction. The subgrade will tend to gain some strength with time due to consolidation under fill weight and traffic. Subgrade contamination of the fill will be very minor when fabrics are used.

4. The maximum fabric potential and thus the maximum economy is achieved on low standard roads where high deflections and 4- to 6 inch ruts can be tolerated. Design values of 6.0 and 3.3 C, with and without fabric, can be used.

5. If poor quality fill materials are used, the thickness of good quality base and surfacing required to prevent rutting of the poorer material must be designed using standard design methods.

6. Fabrics should not be used for subgrade restraint when soil CBR is greater than or equal to ($\geqq$) 3 (vane shear cohesion 1500 psf and cone penetrometer $\geqq$ 120 psi). (CBR vane-cone relationships can be approximated using Figure 5).

7. Preliminary information from trial use projects show that the lightweight non-woven fabrics (4 oz per square yard) performed as well as the heavier (8 to 16 oz per square yard) once they were installed.



Thickness Design Curve For 10,000 lb. Wheel Load

Figure 5 (from Barenberg)

8. The above design procedure is applicable only to shallow deposits of soft materials. For deeper deposits settlement of the fill must also be considered.

Figure 6 is the Special Project Specification being used on several subgrade restraint projects in Region 6. The specification is necessarily nonrestrictive to determine, through monitoring of these installations, the optimum design specification and construction of these installations.

Minimum fabric strength properties specified in current "Special Use" specifications are:

A. Grab Test, ASTM D-1682 warp and fill (lbs) = 120 minimum.

B. Weight, (oz/yd^2) = 4.0 minimum.

C. Elongation at failure = 50% minimum.

Earth Strengthening:

In this application, fabric is used in a fabric-soil system to strengthen earth materials. The fabric and earth materials are placed in horizontal layers to form a retaining wall structure. The fabric is placed in such a manner that the forward edge of the fabric is lapped over a previously placed berm. Subsequent layers of backfill material, fabric and berms form the structure. At the face of the wall the fabric retains the berm material from running out while in the interior of the fill, fabric tensile strength is developed through friction with the soil layers.

No attempt will be made here to discuss the theoretical concepts on which the design of the wall is based. Suffice it to say the design of the wall is based on the Rankine Theory. Among the considerations in the design are earth pressure, live load pressure, fabric tension and pullout resistance.

The basic design procedure is as follows:

1. Determine the unit weight and friction angle of the backfill material. Note: Only free draining granular materials should be considered for backfill.

2. Develop a lateral earth pressure diagram.

3. Develop a live load lateral pressure diagram. Note: Consider appropriate live loads using legal and oversize loads.

4. Combine earth and live load pressure diagrams into a composite.

5. Determine vertical spacing of fabric layers. Note: The spacing is a function of the fabric strength and the lateral pressure at the middle of a layer.

SPECIAL PROJECT SPECIFICATION

Non-Woven Fabric

6-2302-a

DESCRIPTION:

1.1 This work shall consist of furnishing and installing a non-woven fabric used in the roadbed design shown on drawings and in accordance with these specifications and in reasonable conformity with the lines and grades established.

MATERIALS:

2.1 The type and weight of fabric shall be as shown on drawings.

CONSTRUCTION REQUIREMENTS:

3.1 Surface Preparation: After clearing has been completed, the ground shall be leveled and smoothed to remove humps and depressions which exceed six inches in height and depth. Small pieces of woody debris shall be removed or pushed below the ground level. Light vegetation (grass, weeds, leaves, and fine woody debris) may be left in place. Roadbed sections with sideslopes greater than ten percent shall be graded in accordance with Specification 30-Roadway Excavation, prior to placement of the fabric.

3.2 Fabric Placement: Fabric shall be installed directly on the prepared surface. Longitudinal and transverse joints shall be overlapped at least three feet.

3.3 Covering Fabric: Borrow or base course material shall be placed to designated thickness in one lift and spread in the direction of fabric overlap. Borrow or base course shall be spread in a manner to fill soft or weak bearing areas. Hauling equipment shall not be operated on the fabric until the total thickness of borrow or base course is placed.

3.4 Patching Fabric: Torn, punctured, or separated sections of the fabric shall be repaired by installing a fabric patch over the hole prior to placing the borrow or base course material. The patch shall be at least three feet larger in horizontal dimensions than the hole to be repaired.

Figure 6

6. Determine length of fabric required to develop pullout resistance Note: The length of fabric is a function of the pullout resistance, a factor of safety and calculations involving the unit weight and friction angle of the backfill material.

7. Determine length of overlap for the folded portion at the face Note: The length of overlap is a function of fabric tension, fabric resistance and a factor of safety.

8. Check the external wall stability. Note: The external stability should be checked for overturning, sliding and foundation bearing capacity.

Other Factors:

1. Fabric materials in a wall are subject to degradation from ultra-violet rays. Therefore, the wall face must be coated to provide protection. A 0.25 gal/yd^2 application of CSS-1 emulsified asphalt has provided adequate ultra-violet protection. Gunnite provides the additional benefit of protecting the cloth face from vandalism.

2. Fabrics are manufactured in widths up to 17 1/2 feet. Where greater widths are required, the fabric should be turned so that one piece is used. No longitudinal splices should be made.

   In Region 6 it is recommended that earth strengthening projects be constructed under the trial use program. This will enable the gathering of data on design, construction, and performance. This data base will provide information for refining design procedures and developing standards for future general use.

Erosion Control:

In this application fabric is used to prevent movement of surface soils, remove soil from water flowing over the earth's surface, and promote soil protecting growth.

Figures 6-A and 6-B illustrate the use of fabrics as silt fences and barriers. To be effective: a) all silt carrying surface water must be directed through the fabric, b) the fabric must have openings small enough to trap most of the soil but porous enough to pass the water with only a slight buildup of water pressure, and c) the fence structure must be adequate to support the pressure of the silt and water.

Figure 6-C illustrates the use of fabric ditch liners below culvert outlets to prevent erosion of soil until vegetation can be established. A porous fabric is used to prevent sheet and gully erosion and permit the water to soak into the soil. The fabric is temporary since it degrades in sunlight. As the fabric degrades, its erosion prevention function

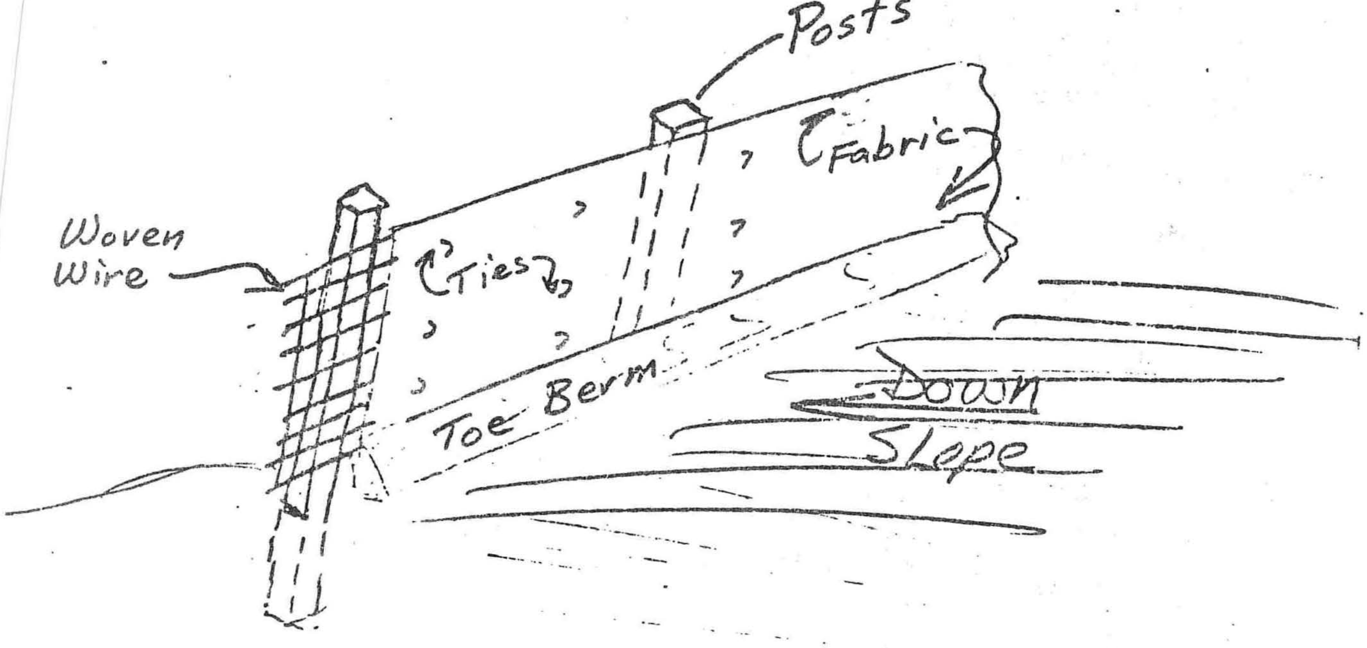


Figure 6-A Silt Fence

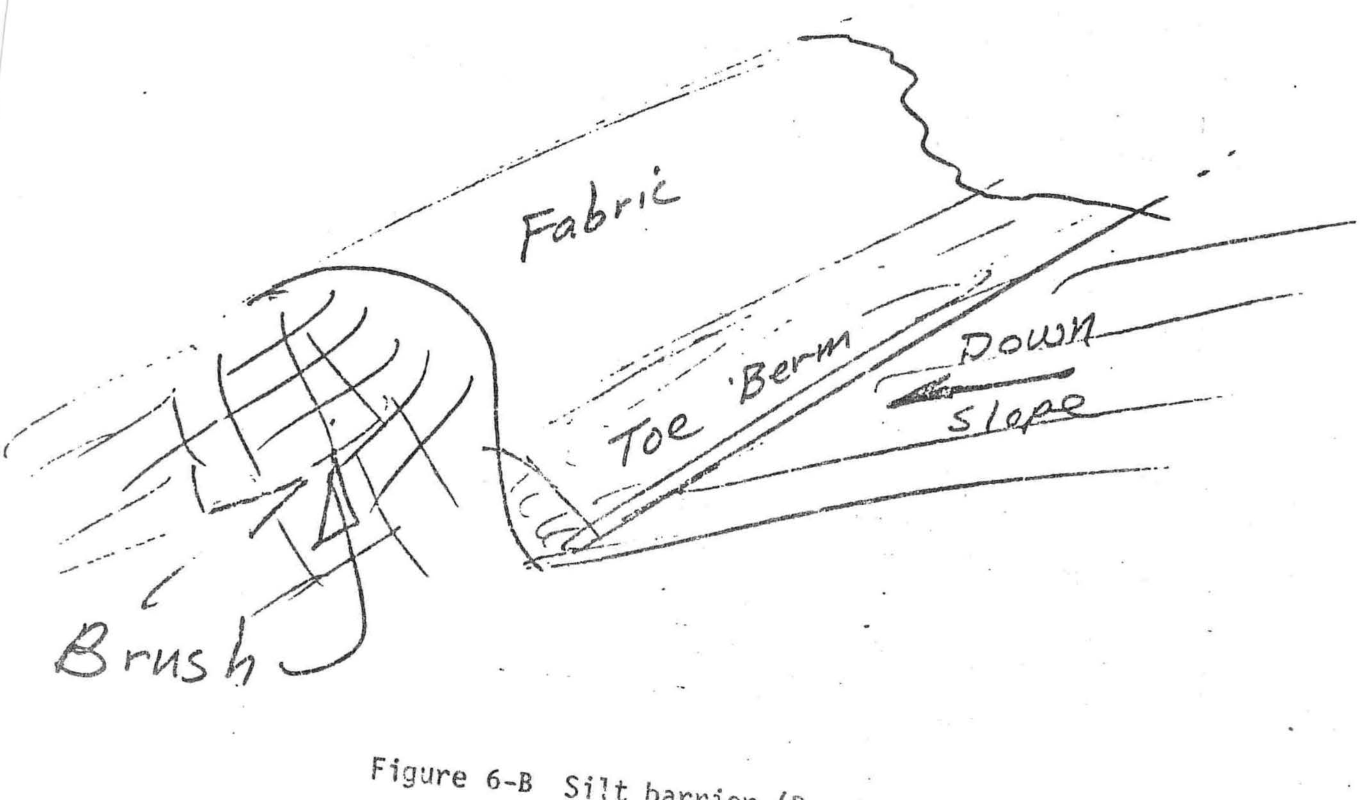


Figure 6-B Silt barrier (Brush)

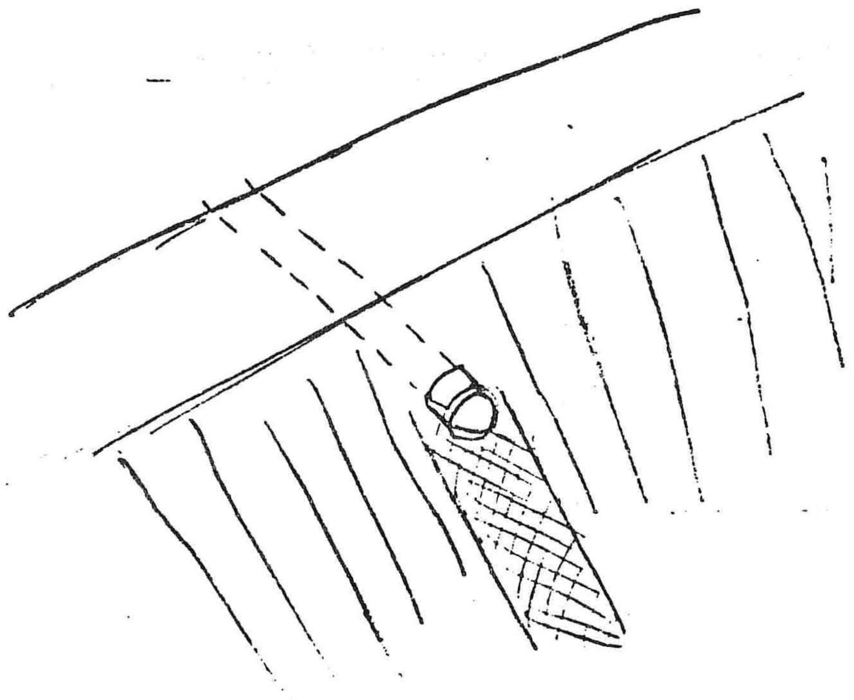


Figure 6-C Fabric Culvert Apron

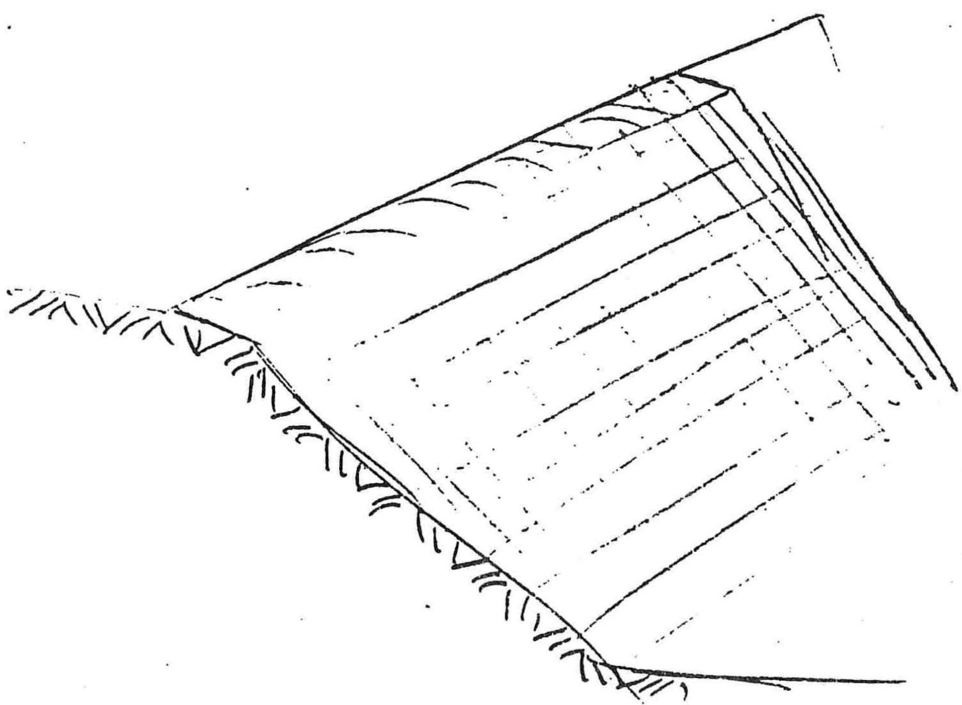


Figure 6-D Fabric Slope Protection
(Erosion Prevention and Mulch).

will be replaced by plant growth. This technique should only be attempted on culverts having low volume intermittent flow in non-critical areas. Water from culverts with heavy flows or located in critical areas should be handled more positively by use of conduits or armored channels.

Another promising area for fabrics in erosion control is their use as a combination mulch and erosion preventor. Materials manufactured for this purpose are generally a light weight woven or non-woven fabric used to hold seed and mulch in place or fabric woven with paper or wood to prevent erosion and act as a mulch (Figure 6-D). The costs for this type of erosion control with fabrics, when compared to other commonly used mulch systems, appear high. However, the fabrics are more positive and consequently more effective on steep erodible slopes. This eliminates the need for replanting as is often required by other mulch systems. Overall, fabrics may be more cost effective than conventional mulch systems.

Fabrics can be used for scour protection beneath revetments and around bridge foundations as illustrated in Figures 6-E and 6-F. The fabric is held in place by rock rip-rap. Both the fabric and rip-rap allow water passage; however, the fabric keeps soil particles from being removed by scour action.

Performance

In general the filter fabrics being used on various Forest Service projects have performed well. As discussed in this report the fabrics are being used for a variety of purposes and are being evaluated under a long term trial use program. Although all of the physical properties of the fabrics that control the performance of the fabrics are not clearly understood, there are certain properties that are fundamental for each specific use. These are shown in Table 2.

Other Performance Information-

1. Fabrics will break down when exposed to sunlight (ultra-violet) for a period of time. The length of time required to break down the fabric depends on the amount and type of stabilizers used in the manufacturing process. Untreated polypropylene and polyester samples left exposed in the field completely disintegrated within 18 months. The polypropylene had noticeable deterioration within two weeks of initial exposure. The fabrics are resistant to most soil and water conditions when protected from sunlight.

2. During installation the higher strain fabrics may resist tearing and punching more than the lower strain fabrics due to their ability to yield and conform to surface irregularities. This is particularly noticeable in the needle-punched non-woven fabrics where the fibers are not tightly gripped. However, recently, one builder of logging roads switched from a 4 oz/yd^2 needle-punched fabric to a 4 oz/yd^2

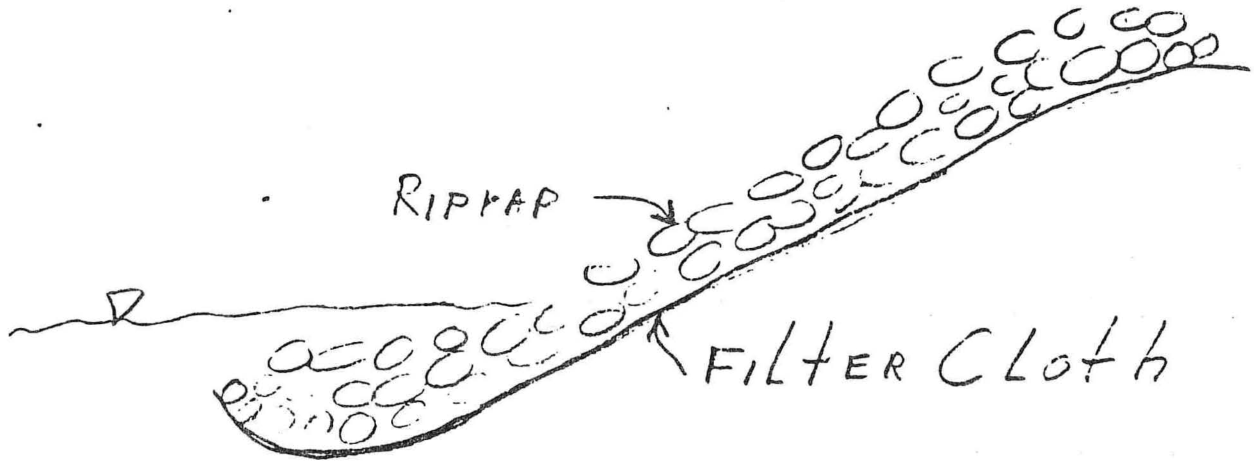


Figure 6-E Revetment

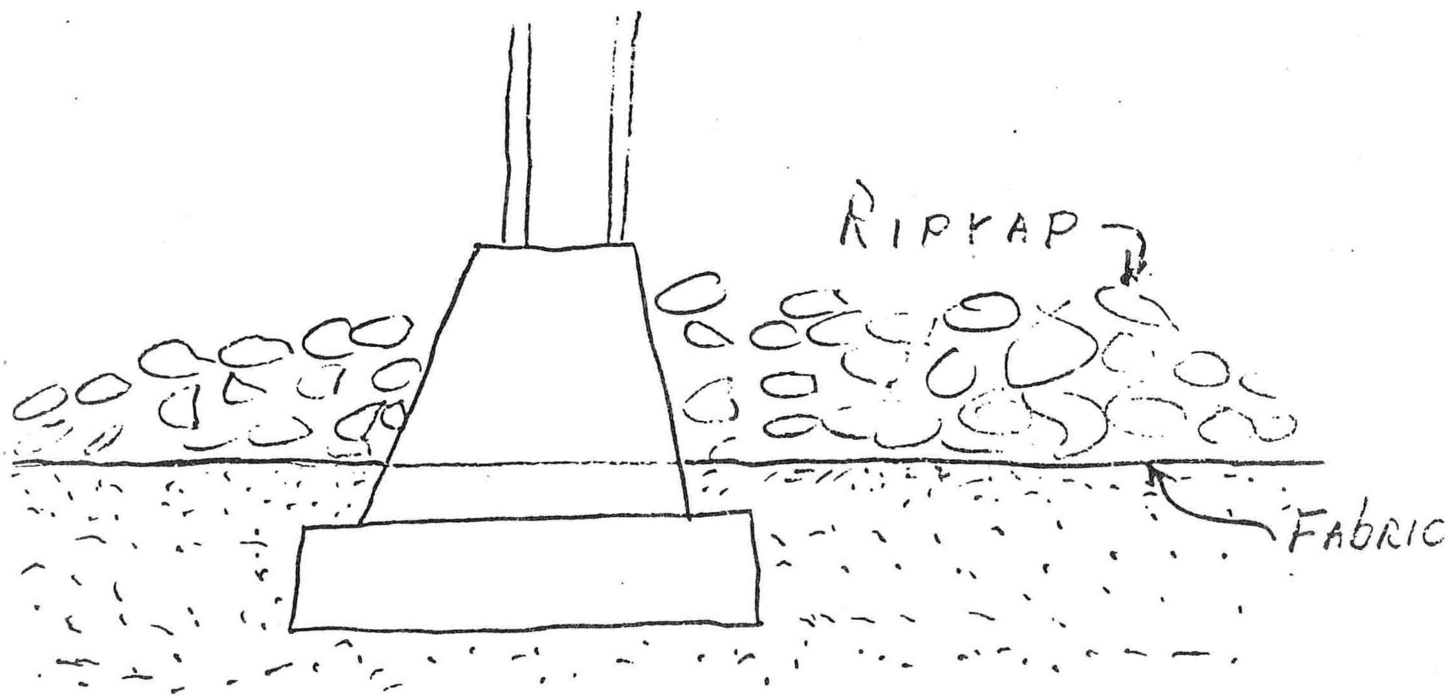


Figure 6-F Scour Protection

Fundamental Fabric Properties as

Related to Specific Uses

Use	Fundamental Fabric Property
Filtration	To remove water without plugging
Separation	To prevent mixing of two dissimilar materials
Subgrade restraint	To be installed undamaged
Earth Strengthening	To have and maintain a predictable, long term, high strength
Erosion control	To prevent or inhibit soil movement

Table 2

heat-bonded because the needle-punched fabric was "too soft" and tended to bulge during rock placement.

Costs and Savings

The costs of fabrics are very dependent on market conditions of supply, demand and competition. Prices fluctuate in response to these conditions. For example in three successive years the price of one manufacturer's woven fabric varied as follows:

Year	Cost per square foot
1974	0.15
1975	0.22
1976	0.12

Barring unforseen circumstances it can be expected that prices will move downward as competition between manufacturers intensifies. Also, as the engineering profession learns more about fabrics it should become possible to specify the particular property or set of properties a fabric should have for a specific intended use. In this way the engineer can get what is needed for a specific use and not pay for other fabric properties that are not needed for that use.

Table 3 shows some ranges of fabric costs and installation costs experienced by the Forest Service in Region 6.

In Region 6 projections have been made of potential savings by the use of fabrics in place of conventional design practices. These potential savings are shown in Table 4. It is evident there are enormous potentials for savings. However, it must be emphasized such savings have not occurred and are only projections of what might occur if fabrics were to be widely used in road construction in Region 6. Nonetheless the potential for such savings amply justify the trial use program currently underway in the Region.

Concluding Statement

Although fabrics are a relatively recent highway construction material, they are becoming increasingly important. State highway departments, the Federal Highway Administration, the Corps of Engineers, the Forest Service and many other highway building agencies have been quick to recognize the potential advantages. These fabrics are highly permeable, strong, flexible and light in weight. They can be used for a variety of purposes in highway construction. Wise and discriminate use of fabrics can result in very large cost savings. Some agencies are routinely using fabrics for certain specific purposes. In the Forest Service woven cloths used for filtration purposes would fall into this category. However, for the most part many agencies including the Forest Service are using fabrics on a trial basis. The fabrics are being evaluated and compared to conventional and traditional ways for handling certain specific design and construction sistuations. There

Materials and Installation Costs for Fabrics

FABRIC OR USE	MATERIAL	INSTALLATION			
	4 oz/yd^2	Trench $\leq$ 5'	Trench $\geq$ 5'	Slope	Subgrade
WOVEN	\$0.12— 0.25/ft^2	\$0.10— 0.10/ft^2	\$0.10— 0.25/ft^2	\$0.03— 0.045/ft^2	\$0.02— 0.035/ft^2
	1.08 — 2.25/yd^2	0.63 — 0.90/yd^2	0.90— 2.25/yd^2	0.30— 0.40/yd^2	0.18— 0.32/yd^2
NONWOVEN 4 oz/yd^2	0.05 0.08/ft^2	Same as Woven			
	0.45 0.72/yd^2				
12 oz/yd^2	0.15 — 0.24/ft^2	25% increase over 4 oz/yd^2			
	1.35 — 2.16/yd^2				
EROSION CONTROL	0.055/ft^2 0.50/yd^2			0.30— 0.045/ft^2 0.30— 0.40/yd^2	
EARTH STRENGTHENING (WALLS)	2.50/ft^2	Excavation 3.35	Backfill 3.35	Labor 2.50	Total \$11.70

(Cost per ft^2 wall face)

Table 3

Potential Saving Using Fabrics
In Region 6, Forest Service

	Range of Savings	
FILTRATION (ground water only, trenches less than 5 feet deep)		
1200 mile/yr @ 100 LF/mile = 120,000 LF/YR		
@ $5/LF 1/	$600,000	
@ $22/LF 2/		$2,640,000
SEPARATION		
600 lane mile/yr		
4 inch rock saving @ $2200/lane mile	1,320,000	
6 inch rock saving @ $8060/lane mile		4,836,000
SUBGRADE RESTRAINT		
200 mile/yr		
@ $7,000/mile 3/	1,400,000	
@$15,800/mile 4/		3,160,000
EARTH STRENGTHENING		
50,000 to 100,000 FT^2 face/yr	300,000	
@ $6/ft^2$ 5/		600,000
TOTAL 6/	$3,620,000-$11,236,000	

Notes:

1/ Assumes all drains-conventional and filter fabric are 100% effective

2/ Assumes conventional drains are 50% effective and filter fabric drains are 100% effective

3/ Assumes pit run (shot) rock in place at $5.00/yd^3$

4/ Assumes minus 6-inch crushed rock in place at $6.50/yd^3$

5/ Assumes $6/ft^2$ savings for fabric walls over conventional walls of same size

6/ Total does not include potential savings for trenches over 5 feet deep, filters for rock buttresses, erosion control, and pavement waterproofing or pavement reinforcement.

Table 4

is every indication that fabrics are more cost effective, easier to use and more "mistake-proof" than many of the traditional means of handling these situations. Because fabrics are a relatively new construction material, they lack long term performance information. When the various highway building agencies have thoroughly evaluated their fabric trial use installations many of the questions on long term performance should be answered.

Of course there is much more to find out about fabrics. What pr perties should a fabric have for the specific design and construction application? Under what conditions are fabrics a viable solution? When should they not be used? What are the appropriate test methods for evaluating the quality and performance of a fabric when the fabric is to be used for highway purposes? What are the appropriate specifications for the intended use of fabrics? The Federal Highway Administration has recently entered into a major research contract with Oregon State University to find answers to these and many other related questions. As these answers become available and the experience base of the highway building agencies increases, it can be anticipated that more specific and better use criteria and specifications will be developed. The major standards writing groups in AASHTO and ASTM are establishing work groups for the development of fabric specifications. All these efforts need to be coordinated so that the research findings are used in the development of meaningful specifications. In addition AASHTO and ASTM groups should work towards the development of a common specification. The interests of the highway community will not be served if fabrics are specified in ASTM and AASHTO by different criteria, different test methods and different ranges of acceptable values.

Forecasting the future has never been an exact science. Nonetheless the future for fabrics for highway construction seems very bright. Over 6 million square yards of fabric were sold in the United Stated in 1976. In 1977 a very conservative estimate of sales would be 10 million square yards. New manufacturers and new models of fabrics are becoming increasingly available. A recent marketing survey estimated over 39 million square yards of fabric will be sold in the United States by 1980. Here again this estimate may prove to be very conservative.

The highway engineering profession in the United States has tended to use fabrics in a very conventional manner for purposes of filtration, separation, subgrade restraint, earth strengthening, erosion control, etc. Other uses are possible, for example:

1. Excavation materials that are normally wasted could be encapsulated by fabrics and incorporated into highway fills.

2. In certain low risk situations, fabrics could be used under and within fills in conjunction with lower quality and consequently less costly construction practices. The fabrics could be used to contain and dampen slumping, settlement, and differential movement

within the fill. The "failures" would be progressive and low level. Repairs could be made where specifically needed thus avoiding costly, overall high quality construction where it is not needed or possible to achieve.

3. Fabric covered drainage grids could be vibrated into the ground thereby avoiding costly excavation and backfill.

4. A biodegradable blanket of fabric with encapsulated and releasable seed, moisture and fertilizer could be placed on erosion sensitive soils. This would promote quick and positive vegetative growth.

5. Fabric impregnated and fabric backed paving materials could be stored in rolls. In accordance with the needs and the situation, "instant pavements" could be laid down, used by traffic and then recovered for further use.

The present and furture uses of fabrics have the potential for significant, cost effective, improvements in highway design, construction and performance. The Forest Service intends to be a part of this technology advancement. It will be up to all of us in the highway community to take full advantage of this new and important construction material.

SELECTED REFERENCES

Barenberg, Ernest J., Dowland Jr., James H., Hales, John H. "Evaluation of Soil-Aggregate Systems with Mirafi Fabric." UIL-ENG-75-2020. University of Illinois at Urbana-Champaign, Urbana, Illinois, August, 1975.

Bell, J. R., and Steward, John E. "Construction and Observations of Fabric Retained Soil Walls." Prepared for the International Conference on the Use of Fabrics in Geotechnics, Paris, France, April, 1977.

Calhoun, Charles C. "Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths." Vicksburg, Mississippi: Army Engineers Waterways Experiment Station, June, 1972.

Calhoun, Charles C., Compton, Joseph R., and Strohm, William E. "Performance of Plastic Filter Cloths as a Replacement for Granular Filter Materials." Highway Research Record No. 373, 1971.

Cedergren, Harry R. "Drainage of Highway and Airfield Pavements." New York: John Wiley and Sons, 1974.

Cedergren, H. R., O'Brien, K. H. and Arman, J. A. "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections." FHWA RD-72-30. Washington, D.C.: Federal Highway Administration, June, 1972.

Greenway, Daryl, R. and Bell, J. R. "Analysis of a Low Fabric Reinforced Embankment on Muskeg." Department of Civil Engineering, Oregon State University, Corvallis, Oregon. June, 1976.

"Guide Specification": Plastic Filter Cloth." Department of the Army; Office of the Chief of Engineers, No. CE1310, March, 1972; No. CE1310, May, 1973; CW-02215, October, 1976.

Howlett, Myles R. "Managing a 200,000-Mile Road System: Opportunity and Challenge." Special Report 160. Washington, D.C.: Transportation Research Board; National Research Council; National Academy of Sciences, 1975.

Marks, B. Dan. "The Behavior of Aggregate and Fabric Filters in Subdrainage Applications." The University of Tennessee, Knoxville, Tennessee, 1975.

Mohney, John M., and Steward, John E. "Fabric Retaining Wall, Olympic National Forest." Portland, Oregon: USDA Forest Service, Region 6, 1977.

Steward, John E. "Plastic Filter Cloths - Some Questions and Answers." Portland, Oregon: U.S. Forest Service, unpublished "White Paper," 1975.

Steward, John E. "Use of Woven Plastic Filter Cloth as a Replacement for Rock Filters." Proceedings of the 27th Annual Highway Geology Symposium, Coeur d'Alene, Idaho, August, 1975.

Steward, John E., Williamson, Ron, and Mohney, John. "Guidlines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads" Portland Oregon: U.S. Forest Service, June, 1977.

Unpublished Notes on Trial Use of Fabrics. Portland, Oregon: USDA Forest Service, Region 6, Engineering, 1977.

Vischer, W. "Use of Synthetic Fabrics on Muskeg Subgrades in Road Construction." USDA Forest Service, Region 10, Juneau, Alaska, November, 1975.

APPENDIX

REGIONAL SPECIFICATION

6-47 PLASTIC FILTER CLOTH

Description

1.1 This work shall consist of furnishing and installing, or installing only, plastic filter cloth used in drainage filtering system designs shown on the Drawings and in accordance with these Specifications and in Reasonable Conformity with the lines and grades established.

Materials

2.1 General. Plastic filter cloth shall be a pervious sheet of plastic monofilament yarn woven into a uniform pattern with distinct and measurable openings. The plastic yarn shall consist of any long-chain synthetic polymer composed of at least 85 percent by weight of propylene, ethylene or vinylidene-chloride, and shall contain stabilizers and/or inhibitors added to the base plastic to make the filaments resistant to deterioration due to ultraviolet and/or heat exposure. The cloth shall be calendered so that the yarns will retain their relative position with respect to each other. The edges of the cloth shall be selvaged to prevent the outer yarn from pulling away from the cloth. The cloth shall be free of defects, rips, holes or flaws.

Purchaser shall furnish a mill certificate or affidavit signed by an official from the company manufacturing the cloth. The mill certificate or affidavit shall attest that the cloth meets the requirements stated in these Specifications.

2.2 Acceptance Testing for Plastic Filter Cloth. All brands of plastic filter cloth to be used shall meet the requirements of this Specification when tested according to the procedures contained in U.S. Army Corps of Engineers document entitled, "Guide Specifications Plastic Filter Cloth," No. CE 1310, May 1973.

2.3 Cloths Tested by Corps of Engineers. The following plastic filter cloths have been tested by Corps of Engineers and found to meet specification requirements for the cloth types listed in Table 3, Section 2.5.

TABLE 1

Cloths Tested by Corps of Engineers

Manufacturer or Fabricator	Trade Name	E.O.S. Sieve No. *	Percent Open Area	Abrasion Resistance **
Carthage Mills, Inc. Erosion Control Div. Cincinnati, OH 45216	Filter X	100	4.6	Low
	Poly-Filter X	70	5.2	High
	Poly-Filter GB	40	24.4	High
Advance Construction Specialties Co. 1050 Texas Street Memphis, TN 38106	Erosion Control Fabric (Type I)	100	4.3	High
Erco Systems, Inc. P.O. Box 4133 New Orleans, LA 70118	Nicolon 66411	30	36.0	Low

*E.O.S. is "equivalent opening size," and is defined as the number of the U.S. Standard Sieve having openings closest in size to the filter cloth opening.

**For "High" Abrasion Resistance, the strength loss after testing shall not exceed 70 percent and the abraded strengths must be no less than 100 lbs. in the stronger principal direction and 55 lbs. in the weaker principal direction.

2.4 <u>Cloth Not Previously Tested</u>. If purchaser elects to use a filter cloth other than listed in Section 2.3, he shall furnish test results performed as prescribed in Section 2.2. Test results shall be furnished at least 60 days prior to installation.

2.5 <u>Physical and Strength Requirements</u>. Plastic filter cloth shall meet the physical requirements listed in Table 2 and the strength requirements listed in Table 3. Unless otherwise shown on Drawings, Type AB filter cloths shall be used.

TABLE 2

Minimum Physical Requirements for Plastic Filter Cloth

Test	Minimum Strength % of Tensile Strength
Alkali Treatment	90
Acid Treatment	90
Low Temperature Treatment	85
High Temperature Treatment	80
Oxygen Pressure Treatment	90
Freeze Thaw	90
Weatherometer	65

	Test Result
Brittleness	No failures at -60° F.
Weight Change in Water	Less than 1.0%

TABLE 3

Minimum Strength Requirements for Unaged Plastic Filter Cloth

Cloth Type	Pretested Cloths	Stronger Principal Direction (Tensile, Lb.)	Weaker Principal Direction (Tensile, Lb.)	Burst (PSI)	Puncture (Lb.)	Seam Breaking (Lb.)
AB	Poly-Filter X Poly-Filter GB Erosion Control Fabric	200	200	510	125	195
C	Nicolon 66411 Filter X	180	100	250	65	90

2.6 Securing Pins. Pins for securing the cloth shall be of steel, a minimum of 3/16 inch in diameter, and at least 15 inches in length. Other equivalent securing devices may be substituted if recommended by the manufacturer.

Construction Requirements

3.1 Storage. During shipment and storage, cloth shall be wrapped in burlap or similar heavy duty protective covering. The storage area shall be such that the cloth is protected from mud, dirt, dust, and debris.

3.2 Installation. The plastic filter cloth shall be placed in the manner and at the locations shown on Drawings. The surface to receive cloth shall be prepared to a relatively smooth condition free of obstructions, depressions, and debris. The cloth shall be laid loosely, but without wrinkles or creases.

The cloth strips shall be overlapped a minimum of 12 inches at joints. Securing pins shall be inserted through both strips of overlapped cloth at maximum intervals of 3 feet.

Securing pins shall be installed as necessary to prevent slippage of the filter cloth and to attach the cloth to the foundation.

The cloth shall be protected from contamination and from damage during installation of other materials. Materials shall be carefully placed on the cloth by methods that will not cause damage to the cloth.

The installed cloth shall be approved by Forest Service prior to covering or backfilling.